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(54) **Method and apparatus for predicting temperatures of a food product**

(57) A method for predicting the equalised temperature of an item during processing of the item comprising the steps of applying a thermal shock to the item;

measuring the surface temperature of the item over time; calculating a predicted value for the equalised temperature of the item based on the rate of change of the surface temperature of the item over time

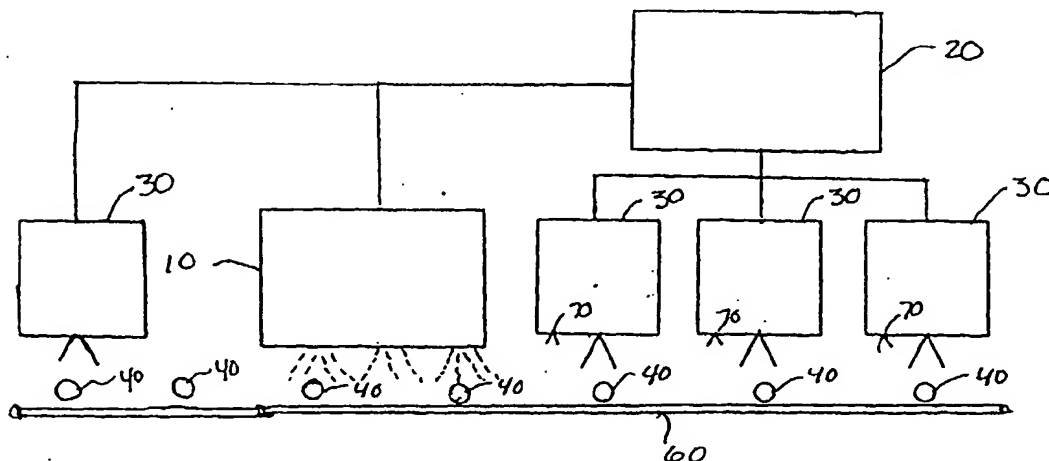


FIG. 1

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Description

[0001] This invention relates to a method and apparatus for determining a prediction of the equalised temperature of a food product prior to its reaching its thermal equilibrium. More specifically, this invention is a method and apparatus for predicting such an equalised temperature based on the response of the food product to thermal shocks.

[0002] The food industry produces a large quantity of standardised food products. In order to control the processes used to make standardised food products, the industry is relying to a greater extent on electronic control systems which monitor various food manufacturing processes and input variables in order to control the quality of the food product as well as to minimise waste and decrease costs.

[0003] One problem associated with the processing of food items is the determination of an equalised temperature of food item. The need for temperature measurement is particularly acute in the area of food cooking and/or frying systems where high heat transfer rates result in a significantly hotter surface surrounding a cooler core. The general aim is to reach a certain equalised temperature for the entire food item which takes a certain amount of time to achieve while also minimising the amount of energy required to achieve the equalised temperature. Likewise, for cryogenically cooled or frozen foods, there is a general need for the food items to reach a certain equalised temperature specified by the needs of the food item while using the least amount of cryogen.

[0004] An intrusive method of temperature determination such as the insertion of a temperature probe in to a food item has severe limitations in measuring the equalised temperature of a food item particularly in a continuous food processing environment. The temperature probe must be manually inserted into a food item which cannot then be further processed resulting in waste. In addition, the amount of effort needed to monitor a significant number of food items invasively would be prohibitively expensive. Furthermore, the actual equalised temperature can only be measured after a certain amount of time passes, for example ten to twenty minutes, and therefore, a large number of food items could be incorrectly processed before an error in the equalised temperature is detected.

[0005] Another known method of temperature measurement, such as a single infrared sensor, would only be capable of measuring the surface temperature of the product and not the equalised temperature throughout the product.

[0006] There is therefore a need for a method and apparatus which enables a food processor to predict or estimate the equalised temperature of a food item in a food processing line in a continuous manner without diverting actual food items from the processing line and using intrusive manual temperature testing. Furthermore, the method and apparatus should allow the food processor to predict the equalised temperature of the food items immediately after a thermal shock is applied, i.e. cooking or cooling, rather than after they have actually reached their equalised temperature, so that problems with the cooking process or cooling/freezing cryogenic process can be corrected.

[0007] The invention is therefore concerned with the provision of a method and apparatus for continuous prediction of and estimating the equalised temperature of a food item during processing including doing so in conditions of variable air flow and variable temperatures found in food processing.

[0008] In accordance with the invention, there is provided a method for predicting the equalised temperature of an item during processing of the item comprising the steps of applying a thermal shock to the item; measuring the surface temperature of the item over time; calculating a predicted value for the equalised temperature of the item based on the rate of change of the surface temperature of the item over time.

[0009] The method advantageously further comprises the steps of applying at least one additional thermal shock to the item and calculating a predicted value for the equalised temperature of the item based on the difference of the rate of change of the surface temperature of the item over time

[0010] The measurement of the surface temperature preferably comprises at least two measurements of the surface temperature of the item over time. More preferably at least two measurements are taken in a continuous manner; alternatively the measurements may be taken in a discrete manner.

[0011] The step of calculating the predicted value preferably uses at least squares, non-linear regression algorithm.

[0012] The method of the invention can advantageously further comprise the step of using the predicted value for the equalised temperature to control the magnitude and/or duration of the thermal shock applied to the item

[0013] Preferably, a first thermal shock is applied to the item using heat and the predicted value of the equalised temperature is used to control the temperature of the heat applied to the item

[0014] Alternatively, a first thermal shock is applied to the item using heat and the predicted value of the equalised temperature is used to control the duration that the food item is subject to heating, especially when at least two measurements of surface temperature are taken continuously.

[0015] The invention also provides an apparatus for predicting the equalised temperature of an item comprising a means for providing a thermal shock to the item; one or more sensors for determining the surface temperature of the item over time; a means for calculating a predicted value of the equalised temperature of the item based on the rate of change of the surface temperature of the item.

[0016] Preferably the apparatus further comprises a conveyor for moving the items from contact with the means for providing thermal shock to the sensor(s).

[0017] It preferably further comprises an optical sensor for determining when surface temperature should be determined using the sensor(s).

[0018] In separate and preferred embodiment, the invention provides apparatus having an infrared sensor for measuring the surface temperature of a food item and means for applying a heat transfer shock of known quantity to the food item for a set length of time. Preferably at least two measurements of the surface temperature of the item are taken at specific times after the initial thermal shock and the equalised temperature of the food item is mathematically predicted from the two measurements.

[0019] In a further aspect of the invention, the thermal shock and surface temperature measurement process is repeated in order to increase the accuracy of the predicted temperature.

[0020] In another preferred aspect of the invention, multiple surface temperature readings are taken after each application of thermal shock with feedback mechanisms to alter the magnitude of the thermal shock.

[0021] In a further preferred aspect of the invention, a plurality of infrared sensors are mounted over a food processing line so that food items pass under the plurality of sensors and an equalised temperature is predicted for a food item based on the readings from the plurality of sensors.

[0022] In a still further preferred aspect of the invention, the information relating to the predicted equalised temperature of the food product is logged in a computer database for use by the food processing system and for purposes of altering the magnitude of additional thermal shocks to the food items.

[0023] To illustrate the invention and to show how it may be put in to effect, reference will now be made, by way of exemplification only, to the accompanying drawings, in which:

Figure 1 is a diagram of an apparatus for carrying out a method of the invention.

Figure 2 is a graph depicting the temperature curves resulting from the apparatus of Figure 1.

Figure 3 is a diagram of a second embodiment of the invention.

Figure 4 is a graph depicting a plurality of temperature readings taken over time.

Figure 5 is a graph depicting a first set of measured and calculated results.

Figure 6 is a graph depicting a second set of measured and calculated results.

Figure 7 is a flow diagram of the prediction method used in the invention.

Figures 8A and 8B are top plan views of two possible embodiments according to the invention.

[0024] With reference to the drawings, Figure 1 a diagrammatic representation of the an apparatus according to the invention. Food items 40 placed on a conveyer 60 travel under a first infrared sensor 30 which provides a measure of the surface temperature of the food item 40. A thermal shock is applied to the food items 40 through a means for providing a thermal shock 60 which could be a cryogenic sprayer for spraying liquid or vapour phase cryogen on the food items 40 or an infrared heat source for heating the food items 40. There are many means for providing a thermal shock to the food items 40 including but not limited to infrared, microwave, inductive, convective or conductive heating and mechanical refrigeration or cryogenic cooling or freezing. Cryogenic cooling could be accomplished through the use of cryogens such as liquid nitrogen, carbon dioxide snow or liquefied air including synthetic liquid air (SLA). After receiving a thermal shock the food items 40 are carried by conveyer 60 under a series of infrared sensors 30 which each provide a signal to a controller 20 indicative of the surface temperature of the food items 40 over a period of time. This sequence of events can be repeated one or more times.

[0025] The variation of the rate of temperature change can be used to indicate the predicted equalised temperature of the product. The controller 20 can use the data regarding the predicted equalised temperature of the food product or items in order to control the means for providing a thermal shock to the food items 40. The controller 20 could be a programmable logic controller (PLC) or other programmable computer such as a personal computer.

[0026] The process described in respect of Figure 1 results in a graph similar to that of Figure 2. Reading 100 represents the temperature of a food item prior to application of the thermal shock. During time periods 120a a thermal shock is applied to the food items which is a cryogenic shock as depicted in Figure 2 such that the temperature of the food item decreases as depicted in portion 110a of the temperature versus time plot of Figure 2. After application of the thermal shock a series of temperature readings 130 are taken by infrared sensors 30. As expected the readings indicate a warming of the exterior of the food item over time as the heat from the warmer core of the food item is thermally transferred to the exterior of the item. An additional thermal shock during time period 120b decreases the

temperature of the food item 40 as seen in portion 110b of Figure 2. The difference in the rate of change of the temperature readings 130, i.e., the difference between the slopes 150a and 150b is indicative of the core temperature of the product.

[0027] In Figures 3 and 4, a preferred embodiment of the invention in which a means for applying a thermal shock is a cooker 10 which heats food items 40. The food items 40 are then carried by a conveyor 60 under a plurality of infrared sensors 30 which each provide a peak reading (T1, T2, T3, T4) for each food item. A plurality of optical sensors 70 are used to determine when a food item is passing under the infrared sensors 30. Using a set of known factors which are product specific the final equalised temperature is calculated which can be supplied to a memory device 90 for use in the processing of the food items 40.

[0028] To calibrate the series of infrared sensors it is necessary to record a minimum of five sets of temperature readings and the equalised temperature. The data is then supplied to a series of simultaneous equations set forth below in equation [1].

$$T1 \ x_1 + T2 \ x_2 + T3 \ x_3 + T4 \ x_4 = T_{\text{equal}} \quad [1]$$

[0029] Figures 5 and 6 depict data from two sets of experiments comparing measured equalised temperatures with calculated equalised temperatures using the above method. The results show that the equalised temperatures can be predicted within plus or minus 5%.

[0030] Figure 7 is a flow diagram of the method of predicting the equalised temperature of a food item. At steps 200 and 210 an input from an optical sensor 70 indicates when a plurality of food items 40 has exited the means for providing thermal shock 10 and indicates that a plurality of readings T1, T2, T3 and T4 should be input from the infrared sensors 30 in step 220.

[0031] In a continuous process, the readings in step 220 are taken when the optical sensor indicated that the elapsed time since a food item has passed under the sensor is greater than the time necessary for the item to pass under all four infrared sensors 30 (T_N) for a given belt speed (BS). The peak readings of each infrared sensor 30 are then used to calculate the equalised temperature.

[0032] In a discrete process the readings of the infrared sensors are time tagged and recorded at specific times for a specific food item and after all four readings are taken for a specific food item the calculation of the equalised temperature begins.

[0033] Independent of the use of the continuous or discrete method of capturing the temperature readings T1, T2, T3, T4 from infrared sensors 30, the next step is to calculate the Jacobian (J) using three sets of data, time (matrix x), temperature readings T1, T2, T3 and T4 (matrix y) and a convergence criterion, matrix p. The temperature readings T1, T2, T3 and T4 as well as the time at which they were taken are known. The set of convergence criteria, p, is initially a guess which is continuously recalculated until the change in the convergence criteria is negligible. A non-linear regression algorithm based on a Taylor expansion is used where second and higher order terms of the model parameters are neglected on the condition that perturbation in those terms will be small. Thus the Jacobian is represented below in equation [2].

$$J = \begin{bmatrix} \exp(p_0 + \frac{p_1}{\sqrt{p+x}}), & \frac{1}{\sqrt{p+x}} \cdot \exp(p_0 + \frac{p_1}{\sqrt{p+x}}), & -\frac{1}{2} \cdot p_1 \cdot (p+x)^{-\frac{3}{2}} \cdot \exp(p_0 + \frac{p_1}{\sqrt{p+x}}) \\ x_1 & x_2 & x_3 \\ x_2 & x_3 & x_4 \\ x_3 & x_4 & \\ x_4 & & \end{bmatrix}$$

[2]

[0034] After calculation of the Jacobian matrix J for a given set of temperatures, times and convergence criteria (the Jacobian matrix J will be different for different model assumptions) the next step 240 is to calculate the difference (Δy) between the experimental values for y and those predicted by the model using the following equation [3].

$$\Delta y = y - \exp(p_0 + \frac{p_1}{\sqrt{p_2 + x}}) \quad [3]$$

5 [0035] In step 250, a set of corrections to originally predicted values for convergence criteria, p , is calculated using the following equation [4].

$$\Delta p = (J^T \cdot J)^{-1} \cdot J^T \cdot \Delta y \quad [4]$$

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[0036] If Δp is near zero then the equalised temperatures may be calculated. If not, then a new set of convergence criteria is calculated in the $p' = p + \Delta p$. The calculation of the Jacobian matrix, J , and Δy is reiterated until Δp approaches zero at which point the equalised temperature y can be calculated using equation [5].

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$$y = \exp(p_0 + \frac{p_1}{\sqrt{p_2 + x}}) \quad [5]$$

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[0037] Figure 8A depicts the top plan view of a system according to the invention in which food items 40 are conveyed on a belt 60 in direction A. The food items 40 are subject to thermal shocks using a means for applying thermal shocks 10 which as stated above may be a cryogenic sprayer, mechanical refrigerator, fryer, cooker, inductive heating element, conductive heating or cooling element, convection heater, infrared heater or other heating or cooling means. A single infrared sensor 30 is placed so as to measure the temperature of one food item across the width of the belt. Figure 8B depicts a top plan view of a similar system wherein a plurality of infrared sensors 30 are used to measure the temperatures of a plurality of food items across the width of the belt so as to insure that the food items across the belt are being processed in a like manner.

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[0038] In a preferred embodiment of the invention a first means for providing a thermal shock 10 is a cooker, fryer or other heating means which would partially or fully cook a food item. A first Infrared sensor 30 placed after the first means for applying the thermal shock 10 enables the system to predict the equilibrium temperature of the food item 40 after cooking. This will then enable the controller 20 to regulate the amount of cryogen or mechanical refrigeration needed to cool and/or freeze the partially or fully cooked food item using the next means for applying thermal shock 10.

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[0039] A series of means for applying thermal shocks 10 as heat interspersed by sensors 30 can be used to control the final hot temperature of food items 40 while minimising the amount of thermal energy needed to achieve a desired end result. Likewise, a series of means for applying thermal shocks 10 as cold can be used to control the final temperature of food item 40 while minimising the amount of energy needed to achieve the desired end result.

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[0040] In such a cooking then freezing process it is possible to overheat the food thereby increasing the frying cost as well as the cost of energy required to freeze the product. For example where a product is overheated by 10 degrees Fahrenheit in a gas fired cooker where the product is being processed at 5000 pounds per hour it is estimated that the cost of the energy unnecessarily expended exceeds UK£8 (US\$12) per hour.

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[0041] Although the present discussion and embodiments discuss a method of predicting the equalised temperature of a food item the process could be applied to non-food items which are heated or cooled and for which the final temperature of the item is important. The food or non-food items may be liquids, solids or mixtures thereof.

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Claims

1. A method for predicting the equalised temperature of an item during processing of the item comprising the steps of:

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applying a thermal shock to the item;

measuring the surface temperature of the item over time;

calculating a predicted value for the equalised temperature of the item based on the rate of change of the surface temperature of the item over time.

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2. A method according to Claim 1 further comprising the steps of applying at least one additional thermal shock to the item and calculating a predicted value for the equalised temperature of the item based on the difference of the

rate of change of the surface temperature of the item over time.

3. A method according to Claim 1 or Claim 2 in which the step of measuring comprises at least two measurements of the surface temperature of the item over time.

4. A method according to Claim 3 in which at least two measurements are taken in a continuous manner.

5. A method according to Claim 3 in which at least two measurements are taken discretely.

6. A method according to any preceding claim in which the step of calculating the predicted value uses a least squares, non-linear regression algorithm.

7. A method according to any preceding claim further comprising the step of using the predicted value for the equalised temperature to control the magnitude and/or duration of the thermal shock applied to the item.

8. A method according to any preceding claim in which a first thermal shock is applied to the item using heat and the predicted value of the equalised temperature is used to control the temperature of the heat applied to the item.

9. A method according to any preceding claim in which a first thermal shock is applied to the item using heat and the predicted value of the equalised temperature is used to control the duration that the food item is subject to heating.

10. A method according to any preceding claim in which the means for applying a thermal shock to the item applies cold to the item.

11. A method according to Claim 10 in which the means for applying a thermal shock to the item applies a cryogen to the item.

12. A method according to Claim 11 in which the cryogen is one or more of liquid nitrogen, carbon dioxide snow or liquefied air.

13. A method according to any one of Claims 1 to 9 in which the means for applying a thermal shock to the item applies heat to the item.

14. Apparatus for predicting the equalised temperature of an item comprising:

a means for providing a thermal shock to the item;

one or more sensors for determining the surface temperature of the item over time;

a means for calculating a predicted value of the equalised temperature of the item based on the rate of change of the surface temperature of the item.

15. Apparatus according to Claim 1 further comprising a conveyor for moving the items from contact with the means for providing thermal shock to the sensor(s).

16. Apparatus according to Claim 15 further comprising an optical sensor for determining when surface temperature should be determined using the sensor(s).

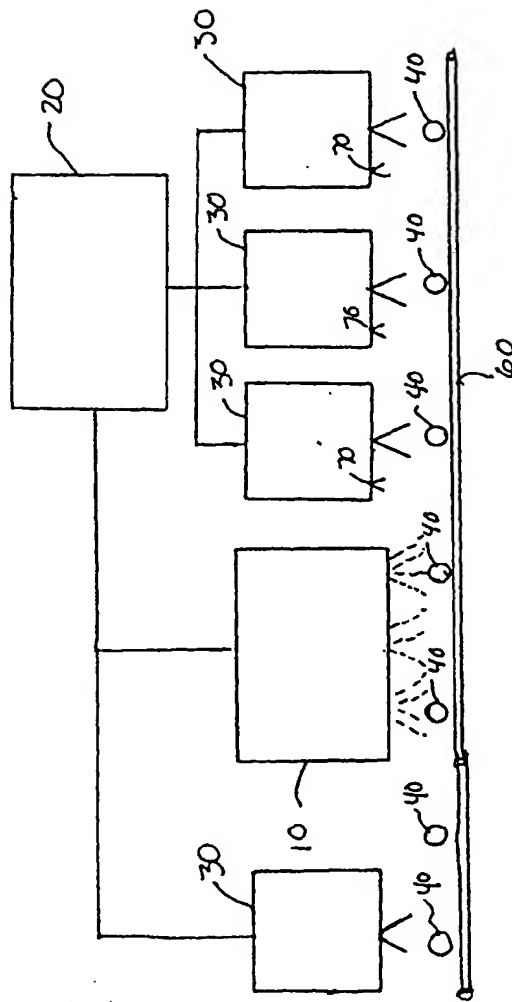
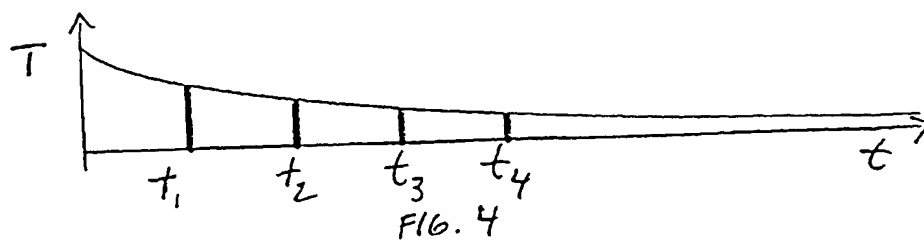
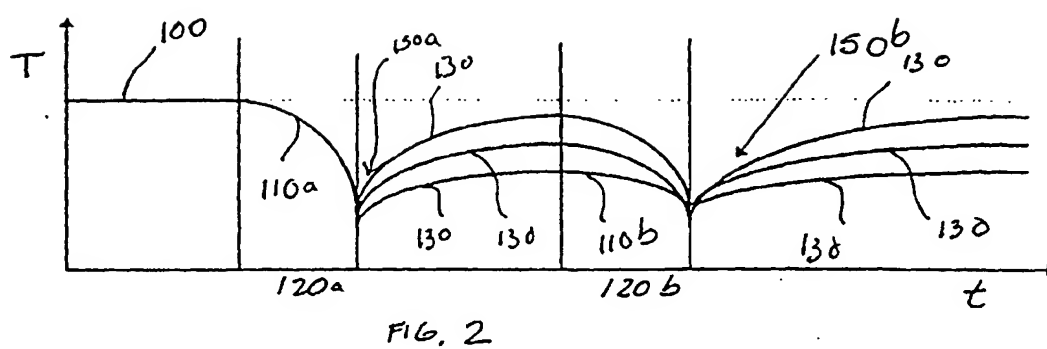


FIG. 1



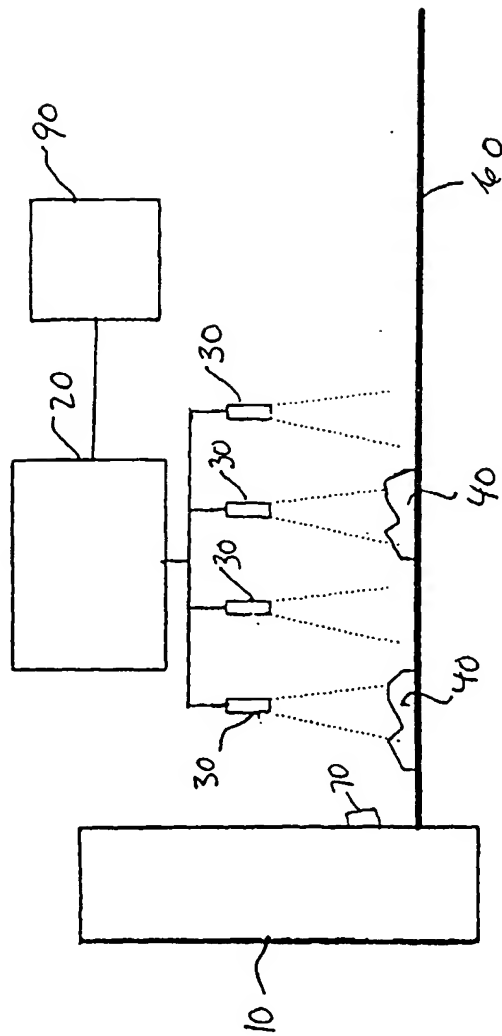


FIG. 3

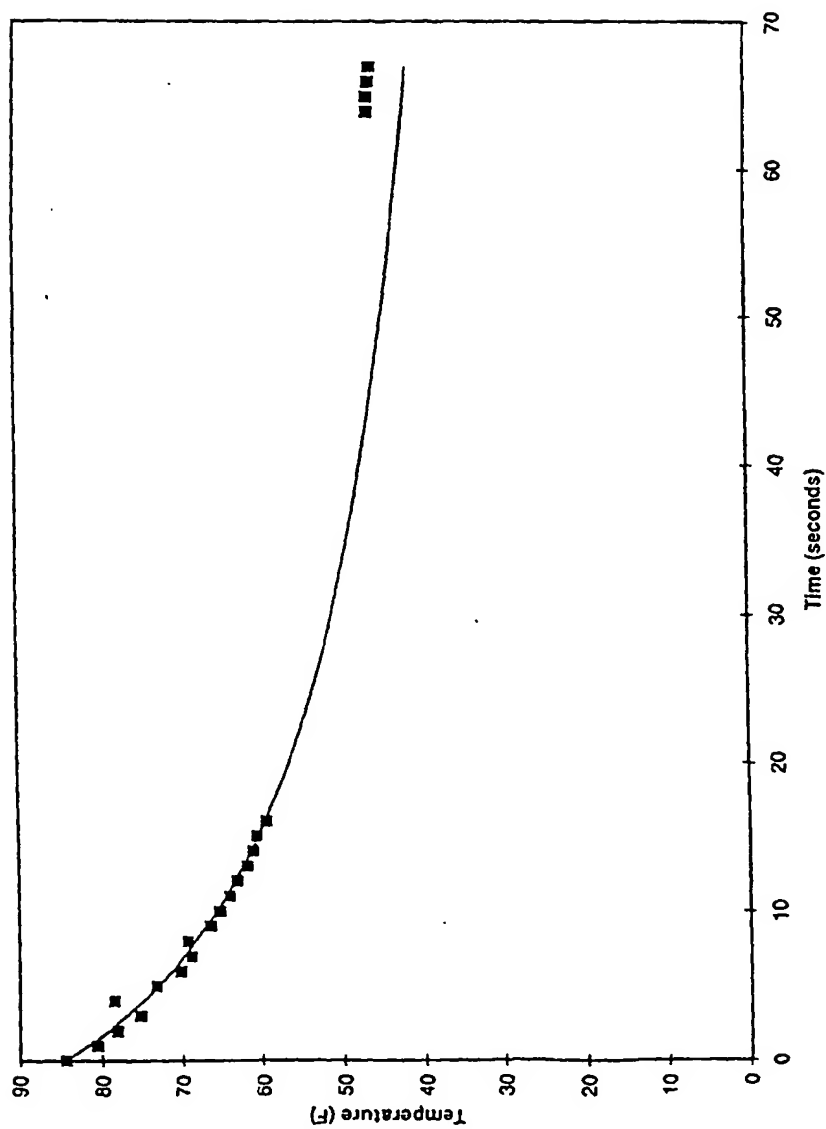


FIG. 5

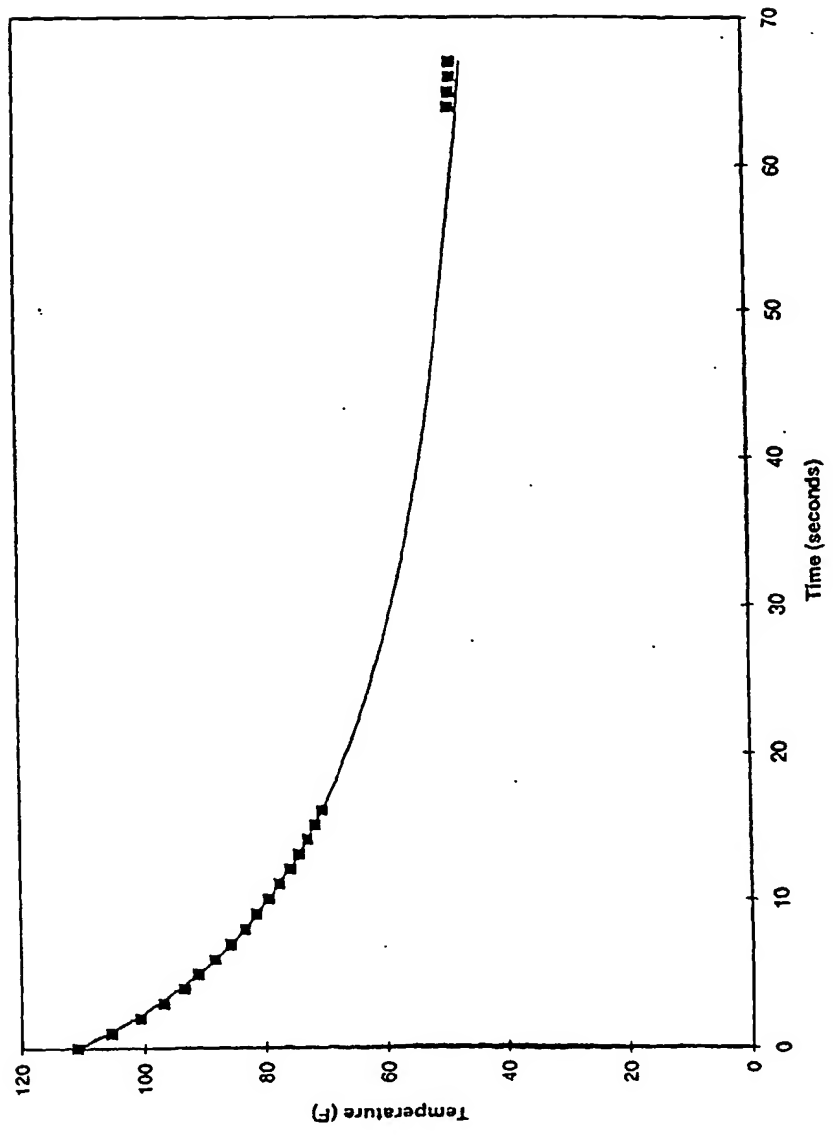
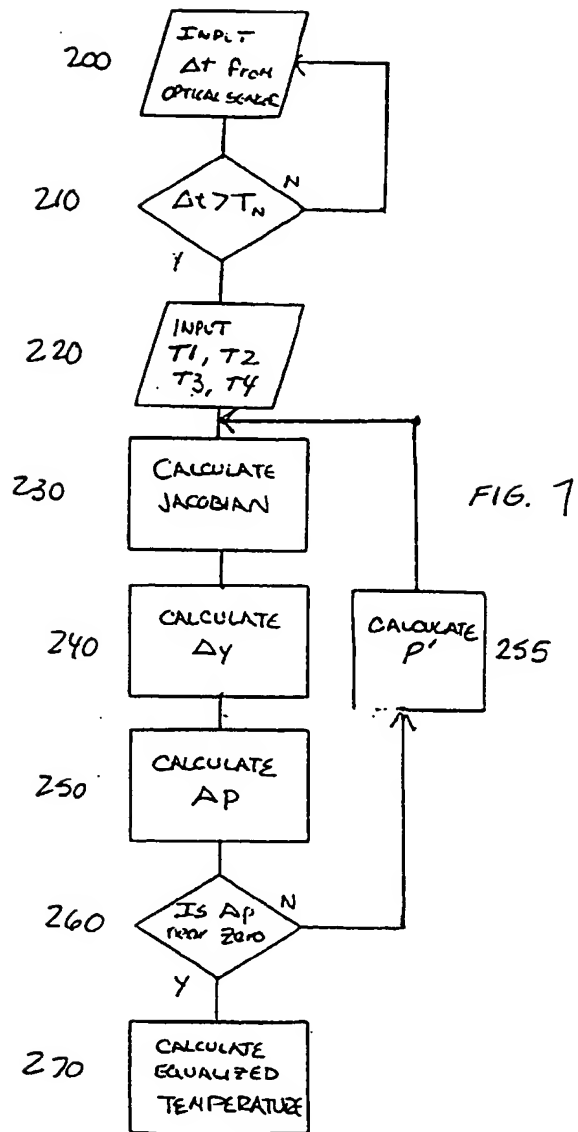
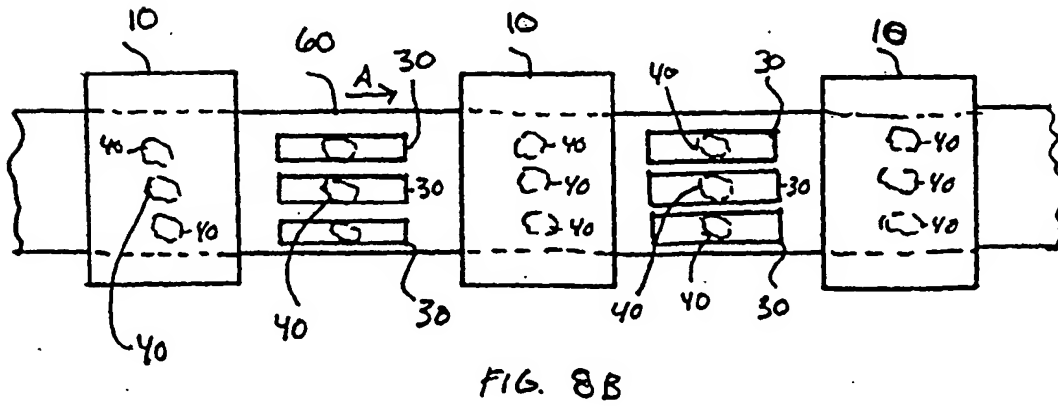
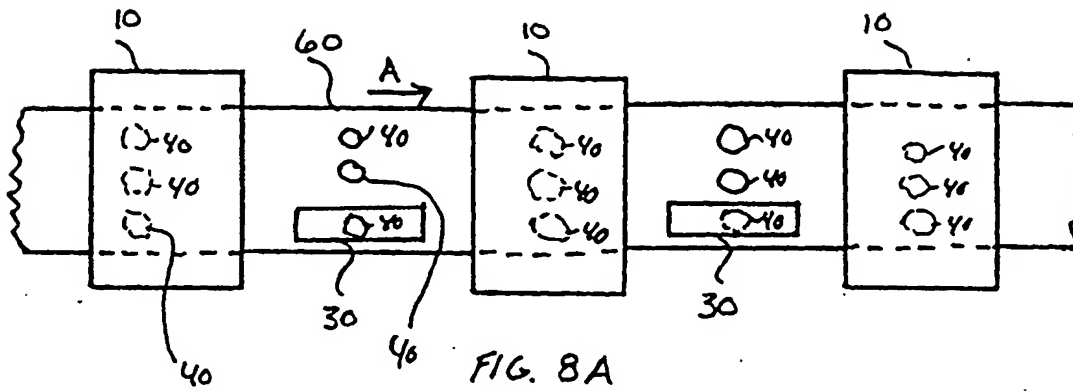


FIG. 6







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EUROPEAN SEARCH REPORT

Application Number
EP 00 31 1166

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 243 (C-1058), 17 May 1993 (1993-05-17) & JP 04 370068 A (MITSUBISHI HEAVY IND LTD; OTHERS: 01). 22 December 1992 (1992-12-22) * abstract *	1,2,13, 14	G01K7/42 A23L1/01
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A	DE 40 32 949 A (MIELE & CIE) 23 April 1992 (1992-04-23) * column 3, line 27 - line 32; figures *	1,5,7-9, 13,14	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 15 March 2001	Examiner Ramboer, P
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